14 COMPLIANCE DEMONSTRATION USING FLIGHT TEST AND SIMULATION

The validation of the performance and integrity aspects FGS operation will typically be accomplished by a combination of the following methods:

- Analysis
- Laboratory Test
- Simulation
- Flight Test

The criteria to be used for establishing compliance with §/JAR 25.1301, 25.1309 and 25.1329 may be found in Sections 8, 9, 10, 11, 12, and 13 of this document. The type and extent of the various validation methods may vary dependent upon the FGS functionality, certification considerations, the applicant's facilities, and various practicality and economic constraints.

This section focuses on compliance demonstration by flight test or simulation with flight crew participation. The section includes the evaluation necessary to confirm acceptable performance of intended functions, including the human-machine interface, and the acceptability of failure scenarios. The specific requirements for flight or simulator evaluation will consider the specifics of the applicant's design, the supporting engineering analysis and the scope and depth of the applicants laboratory testing.

The certification flight test program should investigate representative phases of flight and aircraft configurations used by the FGS. The program should evaluate all of the FGS modes throughout appropriate maneuvers and representative environmental conditions, including turbulence. Combinations of FGS elements (e.g., autopilot engaged and autothrust disengaged) should be considered. Certain failure scenarios may require flight or simulator demonstration. The airplane should contain sufficient instrumentation such that the parameters appropriate to the test are recorded (e.g. normal acceleration, airspeed, height, pitch and roll angles, autopilot engagement state). The flight test instrumentation should not affect the behavior of the autopilot or any other system.

Figure 14-1 depicts the relationship between this section and the rest of the document.

An important part of the pilot in the loop evaluation is validation of human factors. A thorough evaluation of the human-machine interface is required to ensure safe, effective, and consistent FGS operation. Portions of this evaluation will be conducted during flight test. Representative simulators can be used to accomplish the evaluation of human factors and workload studies. The level and fidelity of the simulator used should be commensurate with the certification credit being sought and its use should be agreed with the regulatory authority.

If the FGS includes takeoff and/or approach modes, then the following criteria should be considered for applicability in developing the overall and integrated flight test and simulation requirements:

- Advisory Circular 120-29A, "Criteria for Approving Category I and II Landing Minima for FAR 121 Operators"
- Advisory Circular 120-28D, "Criteria for Approval of Category III Landing Weather Minima" need to be included in the requirements to be tested.
- JAR AWO Subparts 1, 2, 3 and 4
- JAR-OPS 1

AC 25-7A, Flight Test Guide For Certification of Transport Category Airplanes (Section 181, Automatic Pilot System), contains procedures that may be used to show compliance.

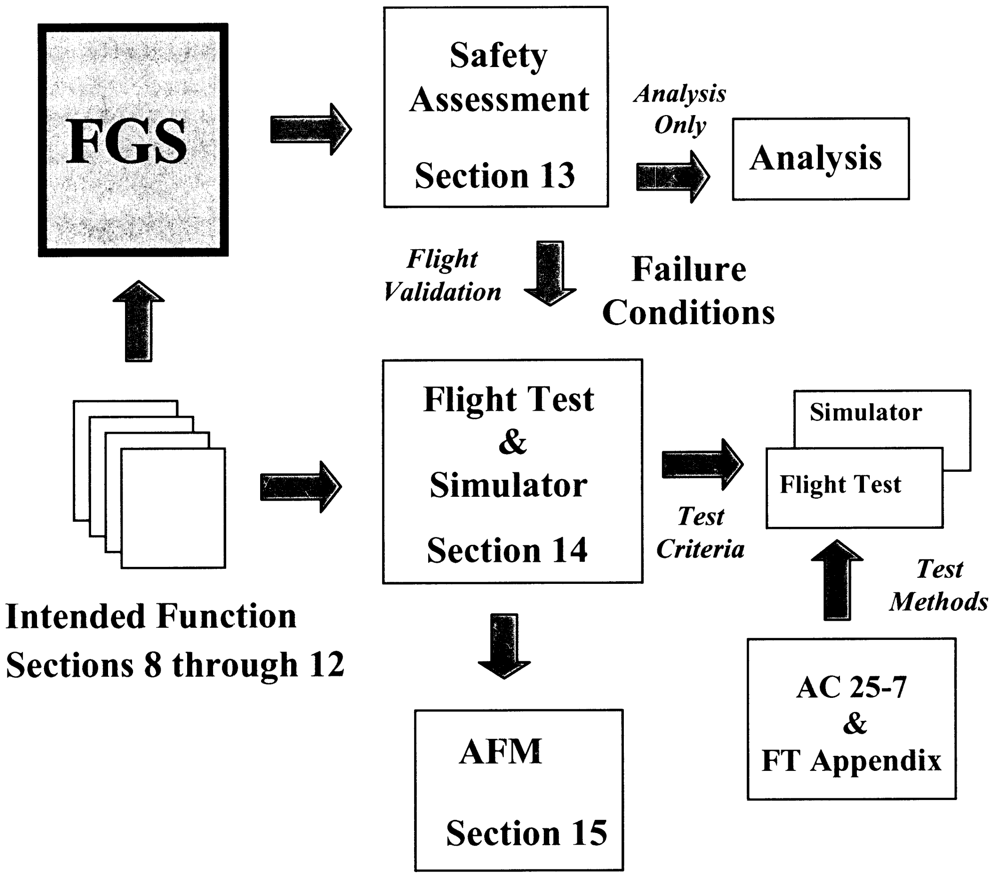

Figure 14-1

14.1 Performance Demonstration (Fault Free) – FAR/JAR 25.1301

The Certification Plan should identify the specific functionality provided by the FGS. The flight test and/or simulator program will typically assess this functionality under representative operational conditions including applicable airplane configurations and a representative range of airplane weight, center of gravity and operational envelope.

The performance of the FGS system in each of its guidance and control modes should be evaluated. The acceptability of the performance of the FGS may be based on test pilot assessment, taking into account the experience acquired from similar equipment capabilities, and the general behavior of the airplane. The level of acceptable performance may vary according to airplane type and model. The FGS should be evaluated for its low and high maneuvering capability. AC 25-7A, Flight Test Guide may provide additional information on FGS test procedures.

The acceptability of mode controls and annunciations, any associated alerts and general compatibility with cockpit displays should be evaluated. The FGS should be free from unexpected disengagement and confusion resulting from changing FGS modes. Additional considerations relating to the assessment of Human Factors is provided in Section 14.5.

14.1.1 Normal Performance

Normal performance is considered to be performance during operations well within the airplane's flight envelope and with routine atmospheric and environmental conditions. Normal performance should be demonstrated over a range of conditions that represent typical conditions experienced in operational use.

The FGS should be evaluated to determine the acceptability of the following characteristics:

- The stability and tracking of automatic control elements
- The flyability and tracking of guidance elements
- The acquisition of flight paths for capture modes
- Consistency of integration of modes (Section 12)

Performance should be assessed in the presence of errors that can reasonably be expected in operation (e.g., mis-selection of approach speed)

14.1.2 Rare Normal Performance

Rare normal performance is considered to be performance of the system under conditions that are experienced infrequently by the airplane during operational use. These conditions may be due to significant environmental conditions (e.g., significant wind, turbulence, etc.) or due to non-routine operating conditions (e.g., out-of-trim due to fuel imbalance or under certain ferry configurations, or extremes of weight and c.g. combinations). Specific rare normal conditions are discussed below

The test program should assess the FGS performance in more challenging operational environments, as the opportunity present itself (e.g., winds, wind gradients, various levels of turbulence). Rare environmental conditions may require the FGS to operate at the limits of its capabilities. The intent of the evaluation is to assess the performance of the FGS under more demanding conditions that may be experienced infrequently in-service.

Due to the severity of some environmental conditions, it is not recommended, or required, that the FGS flight evaluations include demonstration in severe and extreme turbulence, or include flights into microbursts. These conditions are more appropriately addressed by simulator evaluation.

The FGS should be evaluated to determine the acceptability of the following characteristics:

- The stability of automatic control elements and ability to resume tracking following any upset
- The flyability of guidance elements and ability to resume tracking following any upset
- The acceptability of mode transitions and overall cockpit system integration.

14.1.2.1 Icing Considerations

The implications of continued use of the automatic flight control elements of the FGS in icing conditions should be assessed. Ice accumulation on the airplane wings and surfaces can progressively change the aerodynamic characteristics and stability of the airplane. Even though the FGS may perform safely under these conditions, its continued use may mask this change which in turn can lead to pilot handling difficulties and potential loss of control, should the autopilot become disengaged (either automatically or manually).

A test program should assess the potential vulnerability of the FGS to icing conditions by evaluating autopilot performance during ice shape tests or during natural icing tests. Sufficient autopilot testing should be conducted to ensure that the autopilot's performance is acceptable.

In general, it is not necessary to conduct an autopilot evaluation that encompasses all weights, center of gravity positions (including lateral asymmetry), altitudes and deceleration device configurations. However, if the autopilot performance with ice accretion shows a significant difference from the non-contaminated airplane, or testing indicates marginal performance, additional tests may be necessary.

FGS performance and safety in icing conditions should be demonstrated by flight test and/or simulation tests, supported by analysis where necessary.

If significant autopilot inputs are required to compensate for the icing conditions, then the acceptability of the indication of a significant out of trim condition should be made and the subsequent response of the airplane when the autopilot disengages (manual or automatic) should be determined. (Refer to Sections 8.1.2 and 9.3.3)

If the airplane is configured with a de-icing system, the autopilot should demonstrate satisfactory performance during the shedding of ice from the airplane.

Where degradation is noted which is not significant enough to require changes to the autopilot system or to deicing/anti-icing systems, appropriate limitations and procedures should be established and presented in the AFM.

14.1.2.2 Windshear

If the FGS provides windshear escape guidance, performance demonstration requirements should be conducted consistent with AC 25-12.

14.1.2.3 Indication and Response to an Out of Trim Condition

An assessment should be performed to determine the acceptability of the out of trim annunciation and subsequent response to disengagement (Refer to Section 9.3.3).

14.1.3 Specific Performance Conditions

The following paragraphs identify specific performance conditions requiring evaluation by flight test and/or simulation.

14.1.3.1 Low Speed Protection

The FGS should be assessed for the acceptability of the low speed protection performance under the following conditions:

- High Altitude Cruise with a simulated engine failure.
- Climb to Altitude Capture at Low Altitude with a simulated engine failure during capture
- Vertical Speed with insufficient climb power
- Approach with speed abuse

14.1.3.2 High-speed Protection

The FGS should be assessed for the acceptability of the high-speed protection performance under the following conditions:

- High altitude level flight with Autothrust function
- High altitude level flight without Autothrust function
- High altitude descending flight with Autothrust function

14.1.3.3 Go-around

The objective of the go-around mode (refer to Section 11.3.2) is to quickly change the flight path of the airplane from approach to landing to a safe climbout trajectory. The mode has specific utility in low visibility conditions when operations are predicated on a decision altitude/height (DA/H) and a go-around is necessary if visual references are not acquired at the DA/H. Therefore, the assessment of the go-around mode may be conducted in conjunction with the evaluation of the FGS to support low visibility operations, using additional criteria contained in AC 120-28, AC 120-29 and JAR AWO Subparts 2 or 3.

The flight evaluation should be conducted to assess the rotation characteristics of the airplane and the performance of the airplane in acquiring and maintaining a safe flight path. The acceptability of the operation if contact is made with the runway during the missed approach or balked landing should be established.

A demonstration program should be established that confirms acceptable operation when the following factors are considered:

- Airplane weight and CG
- Various landing configurations
- Use of manual thrust or autothrust
- Consequences of thrust de-rates with selection of Go around mode
- An Engine Failure at the initiation of Go-around
- An Engine failure during GA – after go-around power is reached
- Initiation altitude (e.g., in ground effect or not, during flare)

The following characteristics should be evaluated:

- The pitch response of the airplane during the initial transition
- Speed performance during airplane reconfiguration and climbout
- Integrated autopilot and autothrust operation
- Transition to Missed Approach Altitude
- Lateral performance during an engine failure

Where height loss during a go-around maneuver is significant or is required to support specific operational approval, demonstrated values for various initiation heights should be included in the AFM.

14.1.3.4 Steep Approach [Special Authorization]

Typical approach operations include glidepath angles between 2.5 and 3.5 degrees. Application for approval to conduct operations on glidepath angles of greater than 3.5 degrees requires additional evaluation. For such an approval, the FGS flight test and simulator demonstration should include:

- Approach path capture, tracking and speed control

- Recovery of the system from abuse cases e.g. glidepath angle and speed
- Assessment of autopilot disengagement transient
- Demonstration of go-around mode from a Steep Approach

For autopilot use at approach angles greater than 4.5 degrees the requirements of Chapter 8 of FAA AC 25-7A, Flight Test Guide for Certification of Transport Category Airplanes, or equivalent JAA material, should be satisfied. This advisory material contains the airworthiness requirements and transition requirements for steep approaches used to support operational approvals. In addition the requirements of paragraph 6.8 AC 120-29A Appendix 2 (Cat 1)," Criteria for Approving Category I and II Landing Minima for FAR 121 Operators" should be assessed depending on the operational and low visibility requirements.

14.1.4 Flight Director / HUD Considerations

The guidance aspect of an FGS may be provided by a head down Flight Director (F/D) or a Head Up Display (HUD) system. F/D's can utilize various guidance cues (e.g., cross pointer, single cue, flight path vector, etc.) whilst HUD's typically use a symbology linked to a flight path vector. The guidance elements may have a fixed airplane reference (e.g., the traditional F/D) or may use a moving reference such as a flight path vector. Various new display mediums are evolving (e.g., EVS and SVS) that may integrate guidance elements with situational elements.

The flight test or simulator program should demonstrate that the F/D or HUD guidance elements provide smooth, accurate and damped guidance in all applicable modes, so as to achieve satisfactory control task performance without pilot compensation or excessive workload.

The flight director guidance should provide adequate performance for operations with:

- stability augmentation off
- alternate fly-by-wire control modes (e.g., direct law), if any
- an engine inoperative.

Some pilot compensation may be acceptable for these conditions

Flight directors designed to work with a non-stationary tracking reference (such as a flight path angle or flight path vector which are commonly used with HUD guidance) should be evaluated in conditions which bring these guidance symbols to the field of view limits of the display. Crosswinds, and certain combinations of airspeed, gross weight, center of gravity and flap/slat/gear configurations might cause such conditions. At these limits, the dynamics of the guidance response to pilot control inputs can differ with potentially adverse affects on tracking performance, pilot compensation and workload.

Movement of the flight director and its tracking reference should also be demonstrated not to interfere with primary instrument references throughout their range of motion. The pilot's ability to interpret the guidance and essential flight information should not be adversely affected by the movement dynamics or range of motion.

14.1.4.1 Specific Demonstrations for Head-Up Display

These demonstrations are intended to show compliance with the following paragraphs of this AC/ACJ:

- Section 8.2 Flight Director Engagement/Disengagement and Indications, with its subparagraphs
- Section 9.2 Flight Guidance Mode Selection, Annunciation and Indication

- Section 9.4 FGS Considerations for Head-Up Displays (HUD)
- Section 10.1 Normal Performance (specifically criteria for flight director guidance)

When the pilot flying (PF) is using the HUD, the HUD is where the pilot is looking for the basic flight information and the pilot is less likely to be scanning the head down instruments. Therefore:

- It should be demonstrated that the location and presentation of the HUD information (e.g., guidance, flight information and alerts/annunciations) does not distract the pilot or obscure the pilot's outside view. For example, the pilot should be able to track the guidance to the runway without having the view of runway references or hazards along the flight path obscured by the HUD symbology.
- It should be demonstrated that pilot awareness of primary flight information, annunciations and alerts is satisfactory when using any HUD display mode. Some display modes that are designed to minimize "clutter" could degrade pilot awareness of essential information. For example, a "digital-only" display mode may not provide sufficient speed and altitude awareness during high-speed descents.
- It should be demonstrated that the pilot can positively detect cases when conformal symbology is field of view limited.
- Approach mode guidance, if provided, should be satisfactory throughout the intended range of conditions, including at the minimum approach speed and maximum crosswind, with expected gust components, for which approval is sought.
- It should be demonstrated that visual cautions and warnings associated with the flight guidance system can be immediately detected by the pilot flying while using the HUD.
- It should be demonstrated that the pilot flying can immediately respond to windshear warnings, ground proximity warnings, TCAS warnings, and other warnings requiring immediate flight control action, such as a go-around, while using the HUD without having to revert to a head down flight display.

In certain phases of flight, it is important from a flight crew coordination standpoint that the pilot not flying (PNF) be aware of problems with the HUD used by the PF. Therefore it should also be demonstrated that the PNF can immediately be made aware of any visual cautions and warnings associated with the HUD for applicable phases of flight.

If approach mode guidance is provided, satisfactory performance should be demonstrated throughout the intended range of operating conditions for which approval is sought e.g. at the minimum approach speed and maximum crosswind, with expected gust components.

If recovery guidance is provided, it should be demonstrated that the pilot can immediately detect and recover from unusual attitudes when using the HUD. Specialized unusual attitude recovery symbology, if provided, should be shown to provide unequivocal indications of the attitude condition (e.g., sky/ground, pitch, roll, and horizon) and to correctly guide the pilot to the nearest horizon. The stroke presentation of flight information on a HUD may not be as inherently intuitive for recognition and recovery as the conventional head down attitude display (e.g., contrasting color, area fill, shading vs. line strokes). The HUD display design needs to be able to compensate for these differences to provide adequate pilot recognition and recovery cues.

14.1.4.2 Simulator Demonstration for Head-Up Display (HUD)

If a pilot-in-the-loop flight simulation is used for some demonstrations, then a high fidelity, engineering quality facility is typically required. The level of simulator may vary with the functionality being provided and the types of operation being conducted. Factors for validation of the simulation for demonstration purposes include the following:

- guidance and control system interfaces
- motion base suitability
- adequacy of stability derivative estimates used
- adequacy of any simplification assumptions used for the equations of motion;
- fidelity of flight controls and consequent simulated aircraft response to control inputs
- fidelity of the simulation of aircraft performance
- adequacy of flight deck instruments and displays
- adequacy of simulator and display transient response to disturbances or failures (e.g., engine failure, auto-feather, electrical bus switching)
- visual reference availability, fidelity, and delays
- suitability of visibility restriction models such as appropriate calibration of visual references for the tests to be performed for day, night, and dusk conditions as necessary
- fidelity of any other significant factor or limitation relevant to the validity of the simulation.

Adequate correlation of the simulator performance to flight test results should be made.

14.1.5 Flight Crew Override of the Flight Guidance System

A flight evaluation should be conducted to demonstrate compliance with Section 8.4. The flight evaluation should consider the implication of system configuration for various flight phases and operations.

14.1.5.1 Autopilot Override

Effect of flight crew override should be assessed by applying an input on the cockpit controller (control column, or equivalent) to each axis for which the FGS is designed to disengage., i.e. the pitch and roll yoke, or the rudder pedals (if applicable).

If the autopilot is designed such that it does not automatically disengage due to a pilot override, verify that no unsafe conditions are generated due to the override per Section 8.4. The evaluation should be repeated with progressively increasing rate of force application to assess FGS behavior. The effects of speed and altitude should be considered when conducting the evaluation.

If the design of the autopilot provides for multiple channel engagement for some phases of flight that results in a higher override force, these conditions should be evaluated.

NOTE: AC 120-28D, Appendix 3, Section 8 contains guidance for evaluating autopilot override for systems supporting low visibility operations.

14.1.5.2 Autothrust Override

The capability of the flight crew to override the autothrust system should be conducted at various flight phases. The evaluation should include an override of the autothrust system with a single hand on the thrust levers while maintaining control of the airplane using the opposite hand on the control wheel (or equivalent). This action should not result in an unsafe condition per Section 8.4, either during the override or after the pilot releases the thrust levers. If the autothrust system automatically disengages due to the override, the alerts that accompany the disengagement should be assessed to ensure flight crew awareness.

14.1.5.3 Pitch Trim System Evaluation during an Autopilot Override

The effect of flight crew override during automatic control on the automatic trim systems should be conducted. The pilot should then apply an input to the pitch cockpit controller (i.e., control column or sidestick) below that which would cause the autopilot to disengage and verify that the automatic pitch trim system meets the intent in Section 8.4.

If the system design is such that the autopilot does not have an automatic disengagement on override feature, the pilot should initiate an intentional override for an extended period of time. The autopilot should then be disengaged, with the Quick Disconnect Button, and any transient response assessed in compliance with Section 8.4. The effectiveness and timeliness of any Alerts used to mitigate the effects of the override condition should be assessed during this evaluation.

14.2 Failure Conditions Requiring Validation – FAR/JAR 25.1309

The Safety Assessment process identified in Section 13 should identify any Failure Condition responses that would require pilot evaluation to assess the severity of the effect, the validity of any assumptions used for pilot recognition and mitigation. The classification of a Failure Condition can vary according to flight condition and may need to be confirmed by simulator or flight test.

This section provides guidance on the test criteria, including recognition considerations, for flight evaluation of these Failure Conditions. In addition, certain probable failures should be demonstrated to assess the performance of the FGS and the adequacy of any applicable flight crew procedures.

Appendix FT – Flight Test Procedure, provides guidance on test methods for particular types of Failure Condition that have been identified by the Safety Assessment.

14.2.1 Validation Elements

The Safety Assessment described in Section 13 establishes the FGS Failure Condition for which appropriate testing should be undertaken. Assessment of Failure Conditions has four elements:

- Failure Condition insertion
- Pilot recognition of the effects of the Failure Condition
- Pilot reaction time; i.e., the time between pilot recognition of the Failure Condition and initiation of the recovery
- Pilot recovery

14.2.1.1 Failure Condition

Failure Conditions of the autopilot including, where appropriate, multi-axis failures and automatic-trim failures, should be simulated such that when inserted represents the overall effect of each Failure Condition.

Where necessary, Flight Director Failure Conditions should be validated.

The flight conditions under which the failure condition is inserted should be the most critical (e.g., center of gravity, weight, flap setting, altitude, speed, power or thrust). If an autothrust system is installed, the tests should be performed with the autothrust system engaged or disengaged whichever is the more adverse case.

14.2.1.2 Pilot Recognition

The pilot may detect a Failure Condition through airplane motion cues or by cockpit flight instruments and alerts. The specific recognition cues will vary with flight condition, phase of flight and crew duties.

a) Hardover – the recognition point should be that at which a pilot operating in non-visual conditions may be expected to recognize the need to take action. Recognition of the effect of the failure may be through the behavior of the airplane (e.g., in the pitch axis by aircraft motion and associated normal acceleration cues and in the roll axis by excessive bank angle), or an appropriate alerting system. Control column or wheel movements alone should not be used for recognition. The recognition time should not normally be less than 1 second. If a recognition time of less than 1 second is asserted, specific justification will be required (e.g. additional tests to ensure that the time is representative in the light of the cues available to the pilot).

b) Slowover – this type of Failure Conditions is typically recognized by a path deviation indicated on primary flight instruments (e.g., CDI, altimeter, vertical speed indicator). It is important that the recognition criteria are agreed with the regulatory authority. The following identify examples of recognition criteria as a function of flight phase:

- En-route cruise – recognition through the Altitude Alerting system can be assumed for vertical path deviation. The lateral motion of the airplane may go unrecognized for significant period of time unless a bank angle alerting system is installed.
- Climb and Descent – recognition through increasing/decreasing vertical speed and/or pitch or roll attitude or heading can be assumed
- On an Approach with vertical path reference - A displacement recognition threshold should be identified and selected for testing that is appropriate for the display(s) and failure condition(s) to be assessed.

  NOTE:

  (1) For an ILS or GLS approach in a significant wind gradient, a value of 1 dot is considered a reasonable value for crew recognition. In smooth atmospheric conditions with steady state tracking, with the vertical flight path typically maintained at less than a fraction of a needle width, a detection and recognition threshold even below 1/2 dot may be suitable.

  (2) For RNAV systems which do not use dots, some multiple of needle width, related to an established crew monitoring tolerance of normal performance may be appropriate (e.g., x needle widths of deviation on the VNAV scale).

  (3) Credit may be taken for excessive deviation alerts, if available.

- On an Approach without vertical path reference – criteria similar to the climb/descent condition. can be assumed

c) Oscillatory – it is assumed that oscillatory failures that have structural implications are addressed under §/JAR 25.302. It can be assumed that the flight crew will disengage the automatic control elements of the FGS that have any adverse oscillatory effect and will not follow any adverse oscillatory guidance. However, if there are any elements of the FGS that can not be disconnected in the presents of an oscillatory Failure Condition, the long term effects on crew workload and the occupants will need to be evaluated.

14.2.1.3 Pilot Reaction Time

The pilot reaction time is considered to be dependent upon the pilot attentiveness based upon the phase of flight and associated duties. The following assumptions are considered acceptable:

a) Climb, Cruise, Descent and Holding – Recovery action should not be initiated until three seconds after the recognition point

b) Maneuvering Flight - Recovery action should not be initiated until one second after the recognition point

c) Approach - the demonstration of malfunctions should be consistent with operation in non-visual conditions. The pilot can be assumed to be carefully monitoring the airplane performance and will respond rapidly once the malfunction has been recognized. A reaction time of one second between recognition point and initiation of recovery is appropriate for this phase of flight.

NOTE:

(i). For the final phase of landing (e.g., below 80 feet), the pilot can be assumed to react upon recognition without delay.

(ii) For phases of flight where the pilot is exercising manual control using control wheel steering, if implemented, the pilot can be assumed to commence recovery action at the recognition point.

14.2.1.4. Pilot Recovery

Pilot recovery action should be commenced after the reaction time. Following such delay the pilot should be able to return the airplane to its normal flight attitude under full manual control without engaging in any dangerous maneuvers during recovery and without control forces exceeding the values given in §/ JAR 25.143 (c). During the recovery the pilot may overpower the automatic pilot or disengage it.

For the purpose of determining the minimum height at which the autopilot may be used during an approach, or for height loss assessments, a representative recovery appropriate to the airplane type and flight condition should be performed. This maneuver should not lead to an unsafe speed excursion to resume a normal flight path. An incremental normal acceleration in the order of 0.5 g is considered the maximum for this type of maneuver.

14.2.2 Takeoff

The primary concern for the takeoff phase of flight is the effect of the worst case Failure Condition, identified by the Safety Assessment, on the net flight of the airplane after takeoff and the airplane's attitude and speed during climbout. The effects should be evaluated in the pitch up, pitch down and bank as applicable.

If the FGS provides on runway guidance for takeoff, the effect of the failures on that takeoff guidance should be made as identified in AC 120-28D and JAR AWO Subpart 4.

14.2.3 Climb, Cruise, Descent and Holding

Where the Safety Analysis identifies a Failure Condition requiring flight/simulator evaluation with pilot assessment, the height loss should be established in accordance with the method described in the flight test procedures Appendix FT – Section 4.2.3.3.

14.2.4 Maneuvering

Where the Safety Analysis identifies a Failure Condition that has a dynamic effect on the roll control of the airplane, the Failure Condition should be introduced at the bank angle for normal operation. The bank angle should not exceed 60 degrees when the pilot recognition and recover times identified above are applied.

14.2.5 Approach

A discussion of the operational considerations for approach operations is contained in Section 14.3. This section identifies test criteria to support those considerations. The safety assessment process should identify the demonstration of specific Failure Conditions during the approach.

The fault demonstration process during approach should include the four phases identified in Section 14.2.1. The Failure Condition should be inserted at a safe but representative height. The deviation profile should be identified and applied as indicated in the later sections.

14.2.5.1 Approach with Vertical Path Reference

Approach with vertical path reference includes xLS and RNAV operations.

a) xLS (ILS, MLS, GLS)

ILS and MLS operations are typically conducted on instrument approach procedures designed in accordance with United States TERPS or ICAO PANS-OPS criteria, or equivalent. This criteria together with ICAO Annex 14 are generally intended to take into account obstacles beneath a reference obstacle identification surface. It is expected that the same or equivalent criteria will be applied to GLS operations. Hence, in assessing the implication of the effect of failures during autopilot operations a reference 1:29 slope penetration boundary has been applied against the deviation profile to identify an appropriate altitude for continued autopilot operation. The 1:29 slope has been found to provide an acceptable margin above obstacles on an approach.

The worst case Failure Condition identified by the Safety Assessment (see Section 13.4) should be demonstrated against the deviation profile criteria and a Minimum Use Height (MUH) established (See FT Appendix – Section 4.2.3.2).

b) RNAV

For RNAV coupled approach operations, a vertical flight path similar to an xLS flight path will be used (e.g., 3° path starting 50 feet above the threshold). However, due to sensor characteristics it is assumed that RNAV operations will be conducted with a DA(H) or MDA(H) that is higher than an equivalent MUH on an xLS approach to the same runway. Further, for this type of operation it should be noted that the MUH is always in the visual segment of the approach, where the failure recognition and recovery are assumed to be conducted with the pilot having established outside visual reference.

In order to derive only one MUH value for simplicity of use, it is assumed that the effects of failure on the autopilot in RNAV operation are no worse than for the xLS operation, and no further determination or demonstration is required. However, the applicant should show that due account has be taken in the Safety Assessment of the differences between the RNAV and xLS inputs to the autopilot (e.g. barometric altitude input, FMS position and guidance commands, and their failure effects). If these effects can be bounded or otherwise reconciled, then the xLS demonstrated MUH may also be considered applicable to RNAV operations

If these effects can not be bounded or accounted for within those for the xLS operation, the MUH should be determined in accordance with an Approach Without Vertical Path Reference – see below.

14.2.5.2 Approach Without Vertical Path Reference

For an approach without vertical path reference (e.g., VOR, NDB, localizer only) the FGS mode of operation is typically vertical speed/flight path angle (i.e. a cruise mode). The worst case Failure Condition for this type of mode should be demonstrated in the approach configuration, and an appropriate height loss established in accordance with the method described in the Flight Test Procedures Appendix FT – Section 4.2.3.3.

14.2.5.3 Steep Approach

In support of an approval to use the FGS on glidepath angles of greater than 3.5 degrees (see Section 14.1.3.4) an assessment should be made of the effects of failure conditions for this type of operation, For use of autopilot, an appropriate MUH should be established in accordance with the deviation profile method described in Section 14.2.5. For this assessment, the obstacle plane associated with a nominal 3 degree glidepath angle (1:29 slope) should be adjusted according to the maximum approach angle, for which approval is sought.

14.2.6 Specific Conditions

The following are failure conditions that should be considered as part of the FGS evaluation program:

- Engine Failure during approach - continue approach to DA/MDA
- The effect of potential fuel imbalance
- Airplane System Failures (as necessary – requiring specific flight evaluation), e.g.,
  - Hydraulics
  - Electrical
  - Flight Controls
  - FGS related Sensors

The probability of failure of an FGS elements to disengage when the quick disengagement control is operated should be shown to be acceptable by the Safety Analysis process. If credit is to be taken for acceptable continued manual operation with the FGS elements remaining engaged i.e. without operating any of the other disengagement controls, then a flight demonstration should be conducted though approach, landing and rollout.

14.3 Criteria Supporting the Operational Use of an Autopilot

The criteria contained in this section are intended to identify how the functional capability of the FGS, established during the certification, can be utilized to support typical flight operations. The criteria are based on experience gained from certification programs and functionality provided by traditional systems. A FGS providing non-traditional functionality, using new or novel technology, and/or implementation techniques, may require additional criteria to be established.

14.3.1 Autopilot Operations in close proximity the ground

The minimum engagement point for the autopilot after takeoff and the minimum use of the autopilot during approach should take into consideration the effect of:

- Failures and their effects (i.e., Failure Conditions),
- Fault-free performance,

- Any specific operational considerations and/or mitigation.

During low visibility operations, multiple redundant autopilot channels may be used and the effect of any autopilot failures on the flight path may be eliminated, or substantially minimized, by the protection provided be that redundancy. The following considerations apply primarily to single channel operations where performance or integrity aspects may require further consideration. See also Section 13.5.2, which identifies specific considerations relating to autopilot operations close to the ground in the presence of failures.

14.3.1.1 Autopilot Engagement Altitude or Height after Takeoff – Failure Effects

The potential deviation of the airplane from the desired flight path due to the effect of a Failure Condition may necessitate delaying the engagement of an autopilot to an acceptable height above the departure runway.

To support this determination, if an autopilot Failure Condition, or Failure Conditions, are identified that will cause a significant deviation below the intended vertical flight path, the worst-case deviation profile should be identified. This profile and the recovery of the airplane should not result in penetration of the net flight path as defined in §/ JAR 25.115. If the Failure Condition(s) has a neutral effect on the flight path but has implications for speed control during takeoff, the acceptability of cues for the flight crew detection of the condition should be made. The effect of any Failure Condition relating to the bank angle of the airplane should also be assessed. In all of the above, account should be taken of operating the airplane at the WAT limit.

The minimum engagement height will typically be established based on the greater of the following considerations:

- The lowest altitude or height where the flight crew could reasonably be assumed to engage the autopilot. Consideration should be given to normal flight crew tasks during rotation and liftoff (typically 100 feet or greater).
- Any allowance for the acceptability of the performance of the autopilot during the basic engagement/mode transition.
- The lowest altitude or height consistent with the response of the airplane to any identified autopilot Failure Condition(s).
- Activation of stall identification system (e.g. stick pusher) armed (if installed).

If the response to the worst-case failure condition causes a significant transition below the intended vertical flight path, the deviation information should be provided in the AFM.

14.3.1.2 Autopilot Engagement during Approach

The potential deviation of the airplane from the desired flight path due to the effect of a Failure Condition may necessitate the disengagement of an autopilot at an appropriate height on the approach to landing.

The operational minimum engagement height will be established based on the following considerations:

- the altitude or height at which the performance of the automatic control is no longer acceptable,
- the lowest altitude or height consistent with the response of the airplane to a subsequent autopilot failure,
- any specific operational consideration.

The following paragraphs provide assessment criteria for operations that have guidance to the runway threshold, and for those that do not.

14.3.1.2.1 Approach with Vertical Path Reference – Failure Effects

Approaches with vertical path reference can include xLS (i.e., ILS, MLS and GLS) or RNAV. Operations using xLS, can be assumed to be conducted with respect to a flight path prescribed or established as an integral part of navigation service provided by the State of the airport. RNAV approach operations will be conducted using an onboard database that provides a navigation flight path to the runway.

The operational consideration for this type of operations relates an assessment of the adequacy of continued use of the autopilot in maintaining the desired vertical flight path. Considerations include the lowest altitude consistent with the response of the airplane to an autopilot failure.

To support this determination, if an autopilot Failure Condition, or Failure Conditions, is identified that causes a significant transition below the intended vertical flight path, the worst-case deviation profile should be identified using the method identified in Section 14.2.5.1. If the Failure Condition(s) has a neutral effect on the flight path, the acceptability of cues for the flight crew detection of the condition should be made. The effect of any Failure Condition relating to the bank angle of the airplane should be assessed.

For the purpose of the airworthiness assessment, the vertical flight path an xLS and RNAV approach can be assumed to be a flight path of three degrees that passes through the runway threshold at an altitude of fifty feet. Considerations for steep approaches are provided in a subsequent section.

The vertical flight path control for a xLS approach will be made with reference to the path defined by the navigation service. The RNAV vertical flight path will typically be conducted with reference to barometric altitude. An appropriate adjustment to the minimum use height may be appropriate to take into account the vertical accuracy of RNAV operations.

NOTE: Any operational considerations such as extreme temperature effect should be considered in the operational authorization

The Minimum Use Height is the value identified using method identified in Appendix FT - Section 4.2.3.2 [Method 1].

14.3.1.2.2 Approach without Vertical Path Reference

Flight operations with no vertical path reference are conducted with an appropriate visual segment for final approach path. In the interest of providing appropriate automatic control to assist in a stabilized approach, the minimum use of the autopilot should be consistent with the performance needed for the descent (e.g., vertical speed/flight path angle) and the pilot detection and recovery from a autopilot failure.

To support this determination, if an autopilot Failure Condition, or Failure Conditions, is identified that causes a significant transition below the intended vertical flight path, the worst-case deviation profile should be identified. If the Failure Condition(s) has a neutral effect on the flight path but has implications for speed control during takeoff, the acceptability of cues for the flight crew detection of the condition should be made. The effect of any Failure Condition relating to the bank angle of the airplane should be assessed.

For FGS that are failure protected (i.e., fail passive), the minimum engagement height will typically be no lower than 50 feet above runway elevation. However, when determining this limitation, account should be taken of the handling task presented to the pilot when regaining manual control, especially in limiting crosswind conditions.

For FGS that are not failure protected (i.e., not fail-passive), the demonstrated minimum use height will typically be established based on the greater of the following considerations:

a. 50 feet above runway elevation

b. Two times the Height Loss for the airplane as a result of any identified autopilot Failure Condition(s) using the method identified in Appendix FT - Section 4.2.3.3. [Method 2]

14.3.1.3 Circling Approach

For the purposes of this AC, circling approaches may be considered to have three visual segments associated with the approach; a segment at or above the minimums prescribed by the procedure that parallel the runway in the opposite direction of the landing runway, a turning segment to align with the runway that can be level or partially descending, and a final descending segment to landing. Operationally, the autopilot may remain engaged even after leaving the minimum altitude (MDA(H)) for safety and flight crew workload relief reasons. This operational procedure should be balanced against unacceptable performance or failure characteristics. As this procedure is in the visual segment, no specific constraints for the use of the autopilot are considered necessary for this phase of flight unless specific unacceptable performance or failure characteristics related to circling approach are identified during the certification program.

14.3.2 Climb, Cruise, Descent, and Holding

The value of the use of the autopilot in providing flight crew workload relief in climb, cruise, descent and holding phases of flight should be balanced against the failure characteristics of the autopilot. No specific constraints for the use of the autopilot are considered necessary for these phases of flight unless specific unacceptable performance or failure characteristics related to climb, cruise or descent are identified during the certification program.

14.3.3 Maneuvering

No specific constraints for the use of the autopilot are considered necessary for maneuvering flight unless unacceptable performance or failure characteristics are identified during the certification program. Section 14.2.4 provides assessment criteria for maneuvering flight for autopilot failures.

14.4 Automatic Disengagement of the Autopilot

The automatic disengagement characteristics of the FGS should be investigated throughout the flight envelope. Automatic disengagement of the FGS system will occur for several reasons such as system failures, sensor failures, unusual accelerations, etc. These disengagement cases should be analyzed to determine the ones that can safely be demonstrated during the test program. The use of simulation is recommended for all conditions that are expected to result in significant transients. For each disengagement, the transients, warnings, and pilot workload for recovery should be evaluated and compliance with §/JAR 25.1329 (d) and (e) should be verified.

14.5 Assessment of Human Factors Considerations

All new section
14.5

The evaluation, demonstration and testing should assess the acceptability of the human-machine interface with the FGS and the potential for flight crew errors and confusion concerning the behavior and operation of the FGS when used by a representative range of pilots.

The evaluation of normal and non-normal FGS operations should include the representative range of conditions in terms of crew mental or physical workload, required crew response timeliness, or potential for confusion or indecision. The set of test cases should represent operationally relevant scenarios. The test participants should include pilots representing the average pilot in the expected fleet.

Flight evaluation during certification is a final assessment and is intended to validate the design. Prior evaluations are typically conducted in a variety of ways and at different levels of fidelity in order to finalize the design. These may include:

- Engineering evaluations and cognitive task analyses;
- Mock-up evaluations and demonstrations;
- Part-task evaluations and demonstrations;
- Simulator evaluations, demonstrations, and tests; and
- Engineering flight evaluations, demonstrations, and tests.

The data from such evaluations may be useful for credit to establish FGS compliance with regulations having human factors considerations. Also, applicants have successfully used comparisons to previously certificated designs to obtain such credit (although such credit is not assured). Additional testing may be warranted, e.g., for new FGS flight crew interface designs or functions.

In many cases the evaluation, demonstration and test scenarios, including failures and environmental events, will determine whether the data should be obtained in simulation or in flight, because of safety considerations or unavailability of the necessary environmental conditions. In some of these cases a very high fidelity simulation will be needed. In addition to the simulation validation considerations identified in Section 14.1.4.2, the simulation used may need to include the following features, depending on the functionality of the FGS being considered:

- Full physical implementation of flight deck controls, displays, indicators and annunciators for all flight crew positions.
- Adequate emulations of equipment (hardware and software function, including failures) should be incorporated in the simulation.
- Weather simulation including gusts and turbulence.
- Representation of the operational environments, including air traffic, day/night operations, etc, to provide realistic crew workload scenarios.
- Data collection capabilities

Evaluations and tests are intended to generate objective and/or subjective data. It will not always be possible to obtain direct and objective measurements of flight crew performance, even with high fidelity flight or simulation evaluation, demonstration, or test scenarios, and with a broad range of pilots. In these cases, evaluations and tests should be based on the use of structured, subjective methods such as rating scales, questionnaires and/or interviews.

Rationale should be provided for decisions regarding new or unique features in a design. Human factors specialists, together with evaluation pilots, should confirm that the data resulting from the evaluations support acceptability of any new or unique features.

The certification planning documentation should describe the means to show compliance with the HF-related considerations of the FGS with this AC.

See new section 14.5, next page

14.5 Assessment of Human Factors Considerations

The evaluation, demonstration and testing should assess the acceptability of the human-machine interface with the FGS and the potential for flight crew errors and confusion concerning the behavior and operation of the FGS, based on the criteria described in earlier Sections.

The evaluation of normal and non-normal FGS operations should include the representative range of conditions in terms of crew mental or physical workload, required crew response timeliness, or potential for confusion or indecision. The set of test cases should represent operationally relevant scenarios and the assumptions about pilot training and skill level should be documented.

Flight evaluation during certification is a final assessment and is intended to validate the design. Prior evaluations are typically conducted in a variety of ways and at different levels of fidelity in order to finalize the design. These may include:

- Engineering evaluations and task analyses, including cognitive and physical tasks;
- Mock-up evaluations and demonstrations;
- Part-task evaluations and demonstrations;
- Simulator evaluations, demonstrations, and tests; and
- Engineering flight evaluations, demonstrations, and tests.

The data and/or experience from such evaluations may be useful for credit to establish FGS compliance with regulations having human factors considerations. In some cases, certification credit or demonstration of compliance using simulations cannot be granted due to inability to find simulation conformity. In such cases, certification authorities may consider that less flight testing may be required to show compliance if the simulation evaluations have added confidence with respect to the reduced potential for crew error and confusion and other human factors attributes of the pilot/FGS interface. Also, applicants have successfully used comparisons to previously certificated designs to obtain such credit (although such credit is not assured). Additional testing may be warranted, e.g., for new FGS flight crew interface designs or functions.

In many cases the evaluation, demonstration and test scenarios, including failures and environmental events, will determine whether the data should be obtained in simulation or in flight, because of safety considerations or unavailability of the necessary environmental conditions. In some of these cases a very high fidelity simulation will be needed. In addition to the simulation validation considerations identified in Section 14.1.4.2, the simulation used may need to include the following features, depending on the functionality of the FGS:

- Physical implementation of flight deck controls, displays, indicators and annunciators for all flight crew positions that are relevant to the objectives of the evaluation.
- Adequate emulations of relevant equipment (hardware and software function, including capability to introduce failures) should be incorporated in the simulation.
- Weather simulation including gusts, turbulence, windshear and visibility.
- Representation of the operational environments, including interaction with air traffic services, day/night operations, etc, as relevant to the functions and pilot tasks being evaluated
- Data collection capabilities

Simulator evaluations and tests are intended to generate objective and/or subjective data. It may not always be possible or necessary to obtain quantifiable measurements of flight crew performance, even with high fidelity flight or simulation evaluation, demonstration, or test scenarios. In these cases, evaluation procedures should be based on the use of structured, subjective methods such as rating scales, questionnaires and/or interviews. When there is dependence on this type of data, evaluations should consider multiple data collection techniques with an appropriate number of pilot evaluators.

In order to provide sound evaluations, pilots should be trained appropriately on the FGS system operation and procedures. They should also have experience in the kinds of operation and aircraft types for which the

FGS is intended, be familiar with the intended function of the FGS, its operational and design philosophy, and how this philosophy fits with the overall flight deck and its operational and design philosophy.

Rationale should be provided for decisions regarding new or unique features in a design. It should be confirmed that the data resulting from the evaluations support acceptability of any new or unique features.

The certification planning documentation should describe the means to show compliance with the HF-related considerations of the FGS with this AC.